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# HIGH STRENGTH, IMPACT RESISTANT, ELASTIC COMPOSITE LAMINATES

## Field of the Invention

The present invention relates to high impact resistant composite laminate structures.

## Background of the Invention

It is known to utilise physical characteristics of fibre composites to enhance impact resistant properties of, for example, a laminate structure. However, the elastic properties of continuous and unidirectional fibrous composites are highly anisotropic and depend of fibre orientation with respect to the applied stress. The axial tensile strength of a unidirectional lamina is typically controlled by the fibre ultimate strain. The transversal tensile strength of a unidirectional lamina is mainly controlled by the matrix ultimate strain. The strength of a fibre reinforced structure is at least an order of magnitude greater in the longitudinal direction than in the transversal/perpendicular direction to the fibre main axis.

## Object of the Invention

The present invention seeks to provide a new laminate which utilises a composite structure.

## Summary of the Invention

In accordance with the invention, there is provided a high-strength, impact resistant, elastic, fibre composite laminate including at least two inner fibre plies and at least one dissipating element between the inner plies, wherein said at least one dissipating element dissipates and redirects a load applied to the laminate to tensile loading of at least one of said inner plies directed along its longitudinal axis.

In another aspect, there is provided a nanostructure including at least two inner fibre plies and at least one dissipating element between the inner plies, wherein said at least

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one dissipating element dissipates and redirects a load applied to the laminate to tensile loading of at least one of said inner plies directed along its longitudinal axis.

Preferably, the laminate includes a pair of outer layers and a polymer matrix between each of the plies and the outer layers.

In comparison with known structural materials the laminate offers a unique combination of mechanical strength, especially during extreme dynamic loading (impact), with significant weight reduction in comparison with similar samples made from steel or aluminium.

Brief Description of the Drawings

The invention is described by way of non-limiting example only, with reference to the drawings, in which:

Figure 1 is a fragmentary cross-sectional view of a laminate with tubes as dissipating elements.

Figure 2 is a fragmentary cross-sectional view of a laminate with corrugated sheet as dissipating elements.

Figure 3 is a fragmentary cross-sectional view of a laminate with ornamesh/rigidised form as dissipating elements.

Figure 4 is a graph showing the relationship between samples weight and respective impact energy absorbed.

Figure 5 is a graph showing weight comparison between samples.

Detailed Description of a Preferred Embodiment

A laminate structure formed in accordance with the invention represents a new approach in damage tolerant material design philosophy with optional first and second outer face layer for forming an outer face (4), at least two inner plies (2), a dissipating element (1) and usually (dominantly) polymer matrix (3).

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The dissipating elements may be various metal, non-metal, natural and non-natural structures in a form of, but not limited to: expanded metal, ornamesh, rigidised metal, corrugated sheet, tubular shape, spherical shape, other geometric shapes, ribbed, textured, woven mesh (plain, twill square, holander, micron), and any other similar geometric forms, or other structures having the function of dissipation and redirection of local active outer loading (perpendircular/transversal or impact) applied to at least one of the faces, to tensile loading, of at least one of said inner reinforced plies directed along its longitudinal axis.

The outer plies (2) are constructed from a variety of dry or pre-impregnated (prepregs) reinforcement materials such as but not limited to: Glass, Aramid, Carbon, Quartz, Borron, Basalt, Polyurethane, natural, non-natural, and any other single or hybrid fibres, in combination with variety of any known thermosetting and thermoplastic matrixes (3) such, but not limited to: Vinylester, Epoxy, Phenolic, Polypropylene Nylon, Polyester, Amino, Bismaleimides, Polyether, Silicones, Cyanatesters, Polybutadhine, Polyetheramide, Polyimides, fire retardant, corrosion resistant, any sort of adhesives, coatings, pigments, sealants, catalysts, accelerators, diluents, etc.

The optional outer face layers (4) may be made from a variety of any metallic, non-metallic natural or non-natural materials.

The above described laminate structure represents a singular variation of material creation, and there is possibility to apply plurality of plies as described above in any possible direction and combination.

Figure 1 illustrates basic principles of internal force-impact energy dissipation and redirection of local active loading (impact) [F] applied to at least one of the two outer faces of the new structure, to longitudinal (tensile) reaction [Fi] in fibre reinforcement plies in a single structure. These forces are forming force equilibrium as shown on Figure 1 show an example of the laminate structure (7) where the Aluminium tubes (1) are used as dissipating elements.

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Figures 2 and 3 show another two examples (single structure) where applied various metal structures (expanded metal, ornamesh, rigidised forms, corrugated sheets), as the dissipated elements (1), can redirect outer active force/impact energy [F] to the face of the structure, to the tensile force/reaction [Fi] in the longitudinal axis of reinforcement plies (2).

Figure 3 show very high consistency of impact energy absorbed by Strength, Impact Resistant, Elastic Composite Laminate samples.

Figure 4 show significant specific weight reduction of Novel High Strength, Impact Resistant, Elastic Composite Laminate materials in comparison with steel and aluminium.

To further expand on the above, to achieve internal active force/impact energy dissipation and redirection in the laminate (Figure 1) various metallic and non-metallic structures may be used as dissipating elements including but not limited to: expanded metal, ornamesh, rigidised forms, corrugated sheets, tubular shapes, spherical shapes, weave mesh (plain, twill, square, Hollander, micron) metallic or non-metallic foams, foam like structures and any other similar forms (2), and include but are not limited to one or more elements selected from the following metallic, non-metallic, natural and non-natural material groups including but not limited to: aluminium alloys, steel alloys, zinc alloys, titanium alloys, copper alloys, magnesium alloys, nickel alloys, brass alloys, carpenter, gold, silver, platinum, hastelloy, haynes alloy, inconel, molybden alloy, palladium, bronze, tantalum, monel, tungsten, borron, beryllium, zintec, matrix composites, thermoplastics, thermosets, plastics, foams, wood, rubber, paper, ceramics, leather, balsa, cedar, liquids and gases (vacuum) as a single components or compositions.

As a result of loading redirection/dissipation, there are now tensile-reactive forces/loadings in at least one of reinforcement plies directed along its longitudinal axes and, based on mechanical properties of fibre reinforcement materials where the tensile strength of reinforcement materials is at least an order of magnitude higher than transversal strength, the result is the significantly higher strength, especially

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impact resistant, novel laminate structure.[MC1] In comparison with already known/existing composite structures whose major disadvantage is brittleness, the laminate can offer high impact resistance with exceptionally high levels of elastic/plastic deformability and high percentage of elastic recovery after plastic deformation.

With application of this invention, the impact resistance of the laminate does not depend mainly on the matrix's (3) properties; it is now mainly dependable on the fibre reinforcement's mechanical properties.

Specific, desirable properties of new composite structures include:

- redirection and dissipation of outer transversal/perpendicular loading/impact to tensile loading along longitudinal axis in reinforcement inner plies,
- high impact strength,
- high energy-absorbing ability,
- high elastic/plastic deformability under impact,
- high percentage of elastic recovery during plastic deformation,
- low density,
- high tensile strength in all directions,
- high fatigue resistance and durability,
- simple and cost-effective machining and fabricating.

Production of a suitable laminate can include all known processes in composite manufacturing such as, but not limited to: hand lay-up, wet lay-up, spray-up, bag moulding, pressure/vacuum bag moulding, match moulding, press moulding, infusion, open moulding, closed moulding, sequentical moulding, continuous moulding, resin transfer moulding, autoclave moulding.

The laminate structure is made from cost-effective and standard materials readily available and exhibits significant proven improved mechanical properties in comparison with all existing composite laminates.

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With respect to orientation, these internal dissipating elements may be arranged as, but not limited to, unidirectional, cross-ply, symmetric, balanced and quasi-isotropic.

As components in the manufacturing of a diverse variety of laminates it is possible to use any known single or hybrid dry or preimpregnated (prepregs) reinforcement fibres that are made from one or more materials selected from the groups consisting of, but not limited to: Glass (E, S, S-2, T, E-CR), Aramid, Carbon/Graphite, Quartz, Ceramic, PBO, Basalt, Boron, Polyethylene, Natural and hybrid fibre reinforcements (2) as, but not limited to: Quadriaxial, Unidirectional, Double-bias, Biaxial, Triaxial, Plain woven, Woven rovings, Braided, Yarn, 3 Weave rovings, Chopped strands, Mats, simultaneous stitches with use of any known matrixes (3) but not limited to: Vinylester, Epoxy, Phenolic, Polypropylene Nylon, Polyester, Amino, Bismaleimides, Polyether, Silicones, Cyanatesters, Polybutadhine, Polyetheramide, Polyimides, fire retardant, corrosion resistant, any sort of adhesives, coatings, pigments, sealants, catalysts, accelerators, diluents, etc.

With respect to orientation, reinforcement plies may be arranged in a number of ways, including: unidirectional, cross-ply, symmetric, balanced, quasi-isotropic and hybrid laminates.

Optional outer face layers (4), whether for protective or decorative purpose, may be one of the metallic, non-metallic, natural and non-natural materials including, but not limited to: aluminium alloys, steel alloys, zinc alloys, titanium alloys, copper alloys, magnesium alloys, nickel alloys, brass alloys, carpenter, gold, silver, platinum, hastelloy, haynes alloy, inconel, molybden alloy, palladium, bronze, tantalum, monel, tungsten, borron, beryllium, zintec, matrix composites, thermoplastics, thermosets, plastics, foams, wood, rubber, paper, ceramics, leather, balsa, cedar.

The laminate as their integral components may include structures based on a variety of metallic, non -metallic, natural and non-natural materials such as, but not limited to: aluminium alloys, steel alloys, zinc alloys, titanium alloys, copper alloys, magnesium alloys, nickel alloys, brass alloys, carpenter, gold, silver, platinum, hastelloy, haynes alloy, inconel, molybden alloy, palladium, bronze, tantalum, monel,

tungsten, borron, beryllium, zintec, matrix composites, thermoplastics, thermosets, plastics, foams, wood, rubber, paper, ceramics, leather, balsa, cedar, liquids and gases (vacuum) as a single components or compositions.

Nanostructures may be formed as described above, with substitution of expensive materials such as boron, with materials mentioned, to reduce current high prices and make them widely available to industry, but they are not limited only to these components.

As the second stage of fabricating parts/structures with the laminates, it is possible to use most of technologies used in metal and plastics forming processes such as, but not limited to: moulding and stamping, as well as technologies used in cold deformation forming processes such as, but not limited to: blanking, punching, flanging, embossing, bending and drawing.

Primary and secondary structures designed, created and manufactured on the basis of the laminate material design philosophy , can be used in the:

- aviation industry (civil and military),
- space industry (civil and military),
- train and rail industry (civil and military),
- maritime industry (civil and military),
- automotive industry (civil and military),
- all sorts of building industry (civil and military),
- protective industry/ballistic (civil and military),
- construction industry, decoration, machinery, furniture and municipal engineering, road-side safety barriers, and similar,
- multiple general applications,
- materials developed through nanotechnology.

**EXAMPLES**

For example, measured and calculated average properties of laminate sample made from two outer layers of E-Glass quadriaxial woven fibre 1200 gr/m2, one

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internal/dissipation element: Aluminium Ornamesh Type R, and Vinylester resin DERAKANE 411-350, are:

- Tensile Strength $\sigma > 1000$ MPa,
- Density $\rho = 2247$ kg / m3,
- Peak Impact Force F = 184.3 kN (without penetration),
- Impact Energy Absorbed EA = 3985 J (without penetration),
- Deflection 41 mm,
- Young's modulus of elasticity E = 33 GPa,
- Poison's ratio $\nu = 0.33$.

Density of some High Strength, Impact Resistant, Elastic Composite Laminate design solutions may be significantly reduced to 1600 kg / m3.

Table 1. Comparison of selected mechanical properties of materials now in use in the automotive and aviation industries with some of the laminates of the invention.

| Materials | Thickness [mm] | Specific Weight [kg/m3] | Weight per 1m2 [kg/m2] | Absorbed Impact Energy [J] | Specific Absorbed Impact Energy/Weight [J/kg] | Deformation [mm] | Peak Force [kN] | Tensile Strength [MPa] |
|---|---|---|---|---|---|---|---|---|
| Aluminium | 1.5 | 2750 | 4.13 | 0 | 0 | perforated | - | 485 |
| Steel | 0.8 | 7850 | 6.28 | 0 | 0 | perforated | - | 655 |
| Steel | 1.5 | 7850 | 11.78 | 4272 | 1453 | 69 | 133.4 | 655 |
| Honey.Comp. | 4.3 | 1220 | 5.25 | - | - | perforated | - | - |
| Glare-5 | 2.0 | 2590 | 5.18 | 150 | - | perforated | 10.3 | - |
| NHSIRECL 1 | 2.9 | 2247 | 6.51 | 3985 | 1510 | 41 | 184.3 | >1000 |
| NHSIRECL 2 | 5.0 | 1934 | 9.67 | 3778 | 1108 | 13 | 153.9 | >1000 |
| NHSIRECL 6 | 15.2 | 1304 | 19.82 | 3919 | 688 | 29 | 176.0 | >1000 |
| DYN 1 | - | - | - | 3727 | - | perforated | 91.7 | - |
| DYN 5 | - | - | - | 4100 | - | perforated | 69.9 | - |

Legend:

- Data for Glare-5, "Application of Fibre-Metal Laminates", Polymer Composites, August 2000, [Absorbed Impact Energy (maximum) before Perforation],
- Data for DYN 1, and DYN 5 (Structures based on Kevlar reinforcements), form "Impact Testing in Formula One", A. N. Mellor, (Absorbed Impact Energy within displacement of 100 mm) Transport Research Laboratory, Crowthorne, England, ("ICRASH 2002" International Conference, February 2002, Melbourne),
- NHSIRECL – Composite Laminates of the invention.

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Samples (Aluminium, Steel and NHSIRECL) were rigorously tested on a controlled drop weight impact tower with an impactor made from solid steel, weighing 45 kg. The impactor head was formed as sphere of diameter 200 mm. Sample dimensions were 500 x 500 mm. The speed of the impactor at the moment of impact was 55 km/h.

The comparison between Steel sample thickness 1.5 mm and sample NHSIRECL 1 (Table 1), shows that the level of impact energy absorbed by NHSIRECL 1 is 93% of the impact energy absorbed by the Steel sample with 40% lower deflection. At the same time, the weight reduction between NHSIRECL 1 and Steel 1.5 mm is more than 100%.

In comparison with Steel 1.5 mm sample, NHSIRECL 2 shows high level of plastic/elastic deformation, superior deflection reduction with significant weight reduction. Deflection of NHSIRECL 2 is only 20% of deflection recorded by the Steel sample, with 88% of impact energy absorbed of these absorbed by the Steel sample.

Use of the laminates of the invention delivers highly controlled and predictable behaviour under load, accompanied by:

- manufacturing costs can be significantly minimized since known and established manufacturing processes are used;
- manufacturing time can be significantly minimized since known and established manufacturing processes are used and manufacturing simplicity;
- materials costs can be significantly minimized since already available, cost – effective materials are used,
- materials costs can be significantly minimized since reduced number of applied reinforcement plies
- significant finished-product weight reduction;
- demonstrated increases in mechanical properties through its substitution for heavier (steel and aluminium) and more expensive metals;
- expected improved fatigue resistance;
- low maintenance and repair costs;

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- the possibility of innovative cost-saving solutions to design problems now limited by the necessity to use conventional heavier metal sheeting;
- the possibility to manufacture complex sections with reduced number of primary parts in an assembly.

The desirable properties of the laminates (high strength, high impact resistance, elasticity/plasticity) give their user a unique opportunity to create structures exhibiting easily replicated, tightly controlled behaviour under a wide range of loads, especially under extreme impact loading.

The physical properties of the laminates could be widely varied and precisely tailored to the needs of the particular end use application by combining various sorts of materials in large number of permutations for creating new structures.

The result of all above mentioned is an opportunity of global implications for the application and further development of high-tech, high-impact strength, elastic/plastic, cost-effective, lightweight products and components for everyday use in manufacturing, transport, packaging and variety of civil and military industry in general.

Although particular preferred embodiments of the invention have been disclosed in detail for illustrative purposes, it will be recognised that variations of permutations and modifications of the disclosed invention, including the use of various materials/components in creating the laminate lie within the scope of the present invention.